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THE FASTEST FEMALE BUTTERFLY SWIMMERS WERE YOUNGER THAN THE FASTEST MALE BUTTERFLY SWIMMERS

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Abstract

Introduction: The age of peak freestyle swimming speed was reported to be at ~17 years for women and ~19 years for men. However, the age of peak swimming speed for other strokes such as butterfly is not known.

Objectives: We investigated whether the age of peak swimming speed and peak swimming speed changed across years in elite butterfly and freestyle swimmers at national level (Switzerland) between 1994 and 2011.

Methods: Changes in swimming speed and age of the annual ten fastest swimmers across years were investigated using linear regression analyses and two-way analysis of variance (ANOVA).

Results: For both butterfly and freestyle, the age of peak swimming speed was ~19 years for women. For men, the age of peak swimming speed was at ~22 years over all distances with the exception in 200m freestyle with ~21 years. The age of peak swimming speed increased for women in 50m from ~19 years to ~21 years, in 100m and 200m butterfly from ~18 years to ~20 years while it remained unchanged in 50m, 100m and 200m freestyle at ~19, ~18 and ~20 years, respectively. For men, the age of peak swimming speed was constant for butterfly at ~24, ~23 and ~21 years, respectively, and for freestyle at ~23 years in 100m and ~22 years in 200m across years with the exception of a decrease in 50m freestyle from ~23 years (1994) to ~22 years (2011). Both women and men increased peak swimming speed over all distances. Sex difference in peak swimming speed increased in butterfly from 10% in 1994 to 12% in 2011 in 50m to 200m and in freestyle in 100m from 12% in 1994 to 14% in 2011 while it remained unchanged in 50m and 200m freestyle at 12% and 10%, respectively.

Conclusion: To summarize, in butterfly swimming, women seemed to achieve peak swimming speed at ~19 years and men at ~21-22 years. For practical applications, a career as butterfly swimmer may endure longer in men compared to women.

Key words: aging, sex difference, endurance, swimming, peak swimming speed

Introduction

During the past 30 years, numerous studies investigated human limits in various sports such as running [1-3], track and field [4], tennis [4], and swimming [3]. During the 2012 Olympics Games new records for all official Olympic swimming disciplines were set by both women and men [5], providing evidence that peak swimming speed limits have not been reached yet. Years ago, Nevill et al. [3] reported freestyle swimming world record speeds to plateau after significantly improving during the 1960s and 1970s. After the year 2007, a series of new world records were accomplished until FINA [5] restricted the use of full-body, polyurethane, technical swimsuits [6]. Due to this issue some authors excluded data from the years after 2007 into their analyses [7] while others studies are based on rather old data [4]. In other endurance sports such as running, the limits of human running speed were discussed, too. Linear models suggested no limits to human running speed, and that at some point women would run faster than men [8]. On the contrary, Cheuvront et al. [2] concluded that running

speeds by both women and men have already reached a plateau.

Besides the limits of human swimming speed, the age of peak swimming speed is of fundamental and practical interest to both athletes and coaches [9]. It provides insight into the physiology of aging [10-12]. For freestyle swimmers, the age of peak swimming speed was described at ~21 years [13]. However, there seemed to be differences in the age of peak swimming speed for swimmers regarding the length of a swim race. The peak performance in 1,500m freestyle was achieved at a younger age of ~18 years compared to the 50m freestyle at ~23 years, respectively [13]. Fairbrother [14] reported that the age of peak swimming speed for 50m freestyle was achieved in the late 20s and early 30s for men at a considerably higher age than Berthelot et al. described [13].

Peak swimming performance declines with increasing age. After reaching the age of peak swimming speed, swimming speed decreased with increasing age [9,15-17]. For endurance athletes, a peak in swimming speed was described at the age of ~35-40 years with

a linear decrease in until the age of ~70 years [16]. After the age of ~70 years, the decline in swimming speed became exponentially [9,16,18]. The decrease in swimming speed was parallel until the age of ~70 years in both men and women [9,16,18]. However, the age-related decline in swimming speed showed differences regarding the distance and the sex. For example, the age-related decline in swimming speed was greater in 1,500m freestyle than in 50m freestyle [16].

The age of peak swimming speed seemed also to be different regarding the sex of the athletes [4,16] where women seemed to achieve the fastest swimming speeds at earlier ages than men. The analysis of Olympic track and field and swimming data from 1896 to 1980 from Schulz and Curnow [4] revealed that women generally achieved peak swimming speeds at younger ages than men. Schulz and Curnow [4] analysed 100m, 400m and 1,500m freestyle for men and 100m, 400m and 800m freestyle for women, respectively. From 1896 to 1980, the age of peak swimming speed was between 21.4 years (100m freestyle) and 20.3 years (1,500m freestyle) in men and between 19.4 years (100m freestyle) and 16 years (800m freestyle) in women, respectively. Besides the sex differences in the age of peak swimming speed, Donato et al. [16] reported that the age-related rates of decline were greater in women than in men. In women, the decline in swimming speed became progressively greater from 50m freestyle to 800m freestyle and 1,500m freestyle, respectively. In men, no differences were observed in the decline in swimming speed between 100m freestyle and 1,500m freestyle [9].

The change of the age of peak swimming speed across time is a further important topic. Schulz and Curnow [4] found the men's age of peak swimming speed to decrease from 1892-1988 in 100m freestyle from 22.0 years to 20.8 years, in 400m freestyle from 20.4 years to 19.4 years and in 1,500m freestyle from 21.1 years to 19.4 years. For women, however, the age of peak swimming speed increased in 100m freestyle from 18 years to 20.3 years, but decreased in 400m freestyle from 18 years and 17.3 years. For 800m freestyle, there were no data available from 1886-1936 to compare with the second half after World War II.

In other endurance sports disciplines such as running, the age of peak running speed seemed to remain relatively constant over time [4]. The age of Olympic gold medal winners in the men's 100m dash was at ~23 years between 1896 and 1980. Similar results were found for other distances as for short and middle distance running [4], half-marathon running [19], marathon running [20] and ultra-marathon running [21]. In other endurance sports disciplines such as Ironman triathlon, the age of peak swimming speed increased in the swim split across years [22].

The data from Schulz and Curnow for freestyle swimmers [4] showed that the age of peak swimming

speed decreased across years from 1896 to 1980 and women were younger than men when they achieved peak swimming speed. However, newer data from 1980 to 2011 are lacking and it would be interesting to investigate the trends in the last years. The age of peak swimming speed has been investigated for swimmers in freestyle swimming for distances from 50m to 1,500m [4], but not for other strokes such as butterfly. Since results for the age of peak freestyle performance were inconsistent [4,9], the present study investigated race results in butterfly swimming and compared to race results in freestyle swimming of the same period of time (1994-2011) from swimmers of the same country.

Knowledge about the age of peak swimming speed and swimming speed trends may allow athletes and coaches to estimate limits in peak swimming speed. Athletes and coaches may choose appropriate training protocols and realistic goals with this knowledge. Therefore, the aim of the present study was to investigate during the 1994-2011 period the change in age of peak swimming speed changed across years for top ten swimmers at national level (Switzerland) for 50m, 100m and 200m for butterfly and freestyle, respectively, and (ii) the change in peak swimming speed increased across years in 50m, 100m and 200m in butterfly and freestyle. We expected that (i) the age of peak swimming speed would decrease from 1994 to 2011 for both women and men and (ii) peak swimming speed would increase for butterfly and freestyle over 50m, 100m and 200m, respectively.

Methods

Ethics

All procedures used in the study met the ethical standards of the Swiss Academy of Medical Sciences and were approved by the Institutional Review Board of Kanton St. Gallen, Switzerland with a waiver of the requirement for informed consent of the participants given the fact that the study involved the analysis of publicly available data.

Data sampling and data analysis

The data set from this study was obtained from the website of the Swiss Swimming Federation (<http://rankings.fsn.ch/>). The high score list of the Swiss Swimming Federation records annually the fastest race times of each Swiss swimmer for all distances and strokes for short and long course races. Data from long course races were analysed regarding the association between swimming speed, sex and age.

In total, data were available from 1984 to 2011 for 207,852 athletes, including 102,213 women and 105,639 men. Due to the low annual number of swimmers per distance before 1994, we decided to investigate only data between 1994 and 2011, leading to a total number of 204,961 athletes with 100,693

women and 104,268 men. From these athletes, the fastest race times and the race times of the annual top ten athletes for both butterfly and freestyle for three distances (*i.e.* 50m, 100m, and 200m) were determined for both women and men. If there were less than ten women and men for a specific discipline in a year, only the best annual swimming speed was used. In order to compare the swimming speed between the disciplines and distances, race times were transformed to swimming speed as follows: swimming speed (m/s) = [race distance (m)] / [race time (s)]. To compare swimming speeds between women and men, the sex difference was calculated using the equation ([swimming speed in women] – [swimming speed in men]) / [swimming speed in men] x 100. No athlete was included twice or several times in the same year since Swiss Swimming Federation records only the fastest annual race time of the same athlete within the same calendar year.

Statistical analysis

In order to increase the reliability of the data analyses, each set of data was tested for normal distribution and for homogeneity of variances prior to statistical analyses. Normal distribution was tested using a D'Agostino and Pearson omnibus normality test and homogeneity of variances was tested using a Levene's test. To find significant changes in a variable across years, linear regression was used. A two-way analysis of variance (ANOVA) was used to analyse year by year differences between top ten women and top men. Statistical analyses were performed using IBM SPSS Statistics (Version 19, IBM SPSS, IL, USA) and GraphPad Prism (Version 5, GraphPad Software, CA, USA). Significance was accepted at $P < 0.05$ (two-sided for *t*-tests). Data in the text are given as mean \pm standard deviation (SD).

Results

Change in swimming speed

Men were faster than women in both butterfly and freestyle swimming over all distances (Fig. 1 and 2). Both women and men significantly improved swimming speeds over all distances (Fig. 1 and 2, Table 1). Men increased swimming speed in butterfly significantly for 50m, 100m and 200m by 8 mm/s, 6 mm/s and 4 mm/s *per annum*, respectively. Women increased swimming speed for 50m, 100m and 200m by 8 m/s, 4 m/s and 3 m/s *per annum*, respectively. A similar trend in swimming speed was observed in freestyle, where swimming speed increased for men for 50m, 100m and 200m by 7 m/s, 8 m/s and 5 m/s *per annum* and for women by 2 m/s *per annum* over 50m, 100m and 200m, respectively.

Change in the age of peak swimming speed

In butterfly, the age of peak swimming speed increased significantly over all distances in the top ten women. In 50m, the age of peak swimming speed increased from ~19 years (1994) to ~21 years in 2011 and in 100m and 200m from ~18 years (1994) to ~20 years (2011) (Fig. 1 and Table 2). For men, the age of peak swimming speed showed no change in 50m (~24 years), 100m (~23 years) and 200m (~21 years), respectively. In the top ten male freestyle swimmers, the age of peak swimming speed decreased significantly in 50m from ~23 years (1994) to ~22 years (2011) (Fig. 2 and Table 2). The age of peak swimming speed for women showed no change with ~19 years in 1994 *versus* ~20 years in 2011. The age of peak swimming speed remained unchanged in 100m freestyle for both men (~22 years in 1994 *versus* ~23 years in 2011) and women (~18 years in 1994 *versus* ~18 years in 2011). In 200m freestyle, the age of peak swimming

Table 1. Corresponding r^2 , p and slopes values of the linear regressions of swimming speed presented in Fig. 1 (butterfly; panel B, D, F) and Fig. 2 (freestyle; panel B, D, F). *n.s.* = statistically not significant

Distance	Butterfly			Freestyle		
	r^2	P	Slope x 10^{-2}	r^2	P	Slope x 10^{-2}
Men						
50m	0.85	<0.0001	0.79	0.74	<0.0001	0.66
100m	0.90	<0.0001	0.61	0.90	<0.0001	0.75
200m	0.75	<0.0001	0.39	0.90	<0.0001	0.51
Women						
50m	0.81	<0.0001	0.79	0.53	0.0007	0.22
100m	0.72	<0.0001	0.42	0.52	0.0008	0.20
200m	0.66	<0.0001	0.29	0.66	<0.0001	0.24
Sex difference						
50m	0.08	<i>n.s.</i>	4.6	0.55	0.0004	16.31
100m	0.26	0.03	7.1	0.81	<0.0001	22.88
200m	0.24	<i>n.s.</i>	3.7	0.65	<0.0001	12.40

Table 2. Corresponding r^2 , p and slopes values of the linear regressions of age presented in Fig. 1 (butterfly; panel A, C, E) and Fig. 2 (freestyle; panel A, C, E). n.s. = statistically not significant

Distance	Butterfly			Freestyle		
	r^2	P	Slope x 10^{-2}	r^2	P	Slope x 10^{-2}
Men						
50m	0.17	n.s.	-7.0	0.40	0.005	-15.2
100m	0.05	n.s.	-3.5	0.20	n.s.	-7.6
200m	0.03	n.s.	-4.4	0.09	n.s.	-4.8
Women						
50m	0.29	0.02	9.4	0.18	n.s.	7.2
100m	0.55	0.004	13.3	0.07	n.s.	4.9
200m	0.29	0.02	8.5	0.05	n.s.	3.8
Sex difference						
50m	0.32	0.02	-57.3	0.58	0.0003	-86.9
100m	0.31	0.02	-57.4	0.24	0.04	-51.3
200m	0.25	0.04	-50.2	0.37	0.007	-58.8

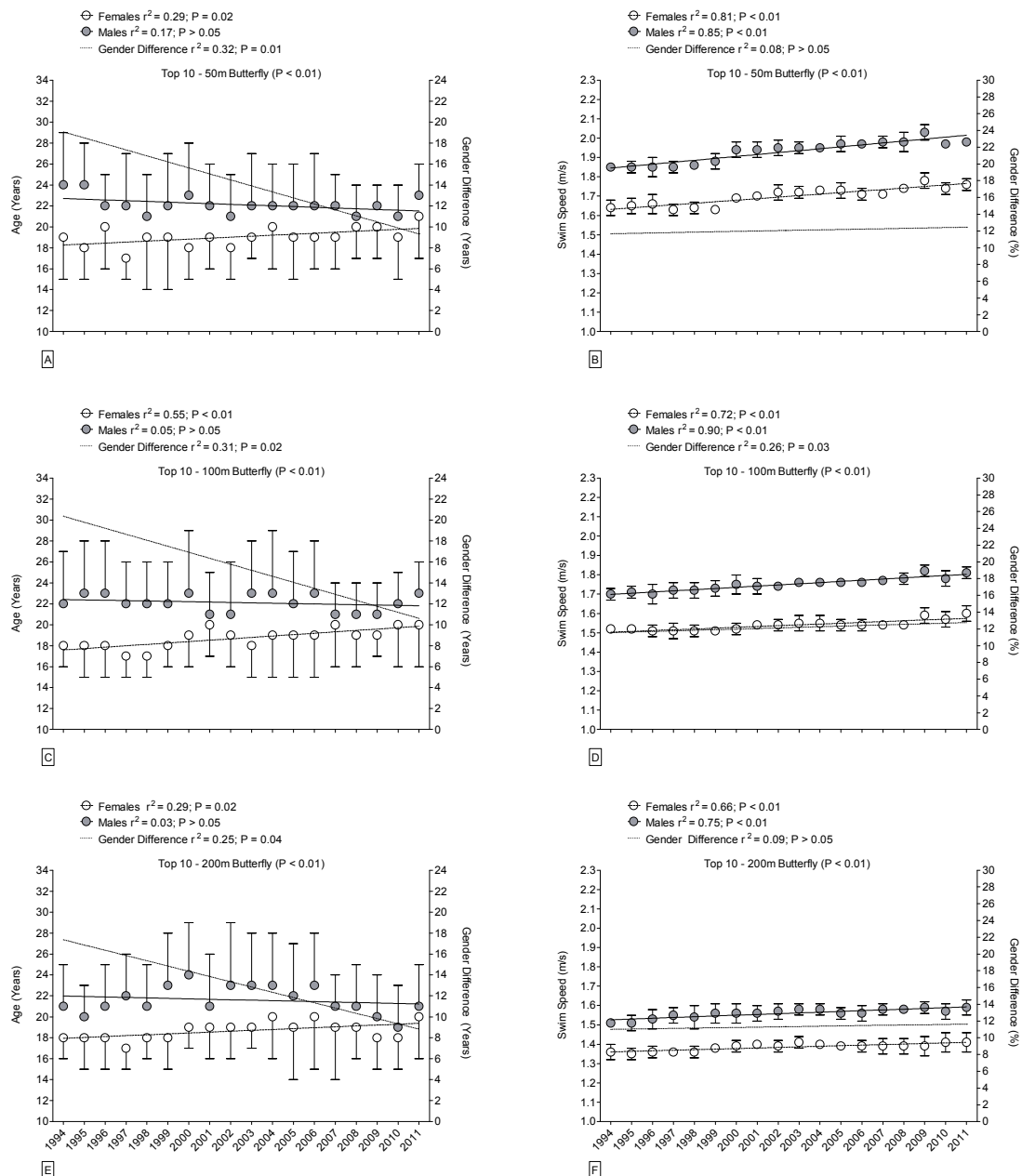


Fig. 1. Age (Panels A,C,E) and swimming speed (Panels B,D,F) of the annual top ten women and men with sex difference for butterfly in 50m, 100m and 200m

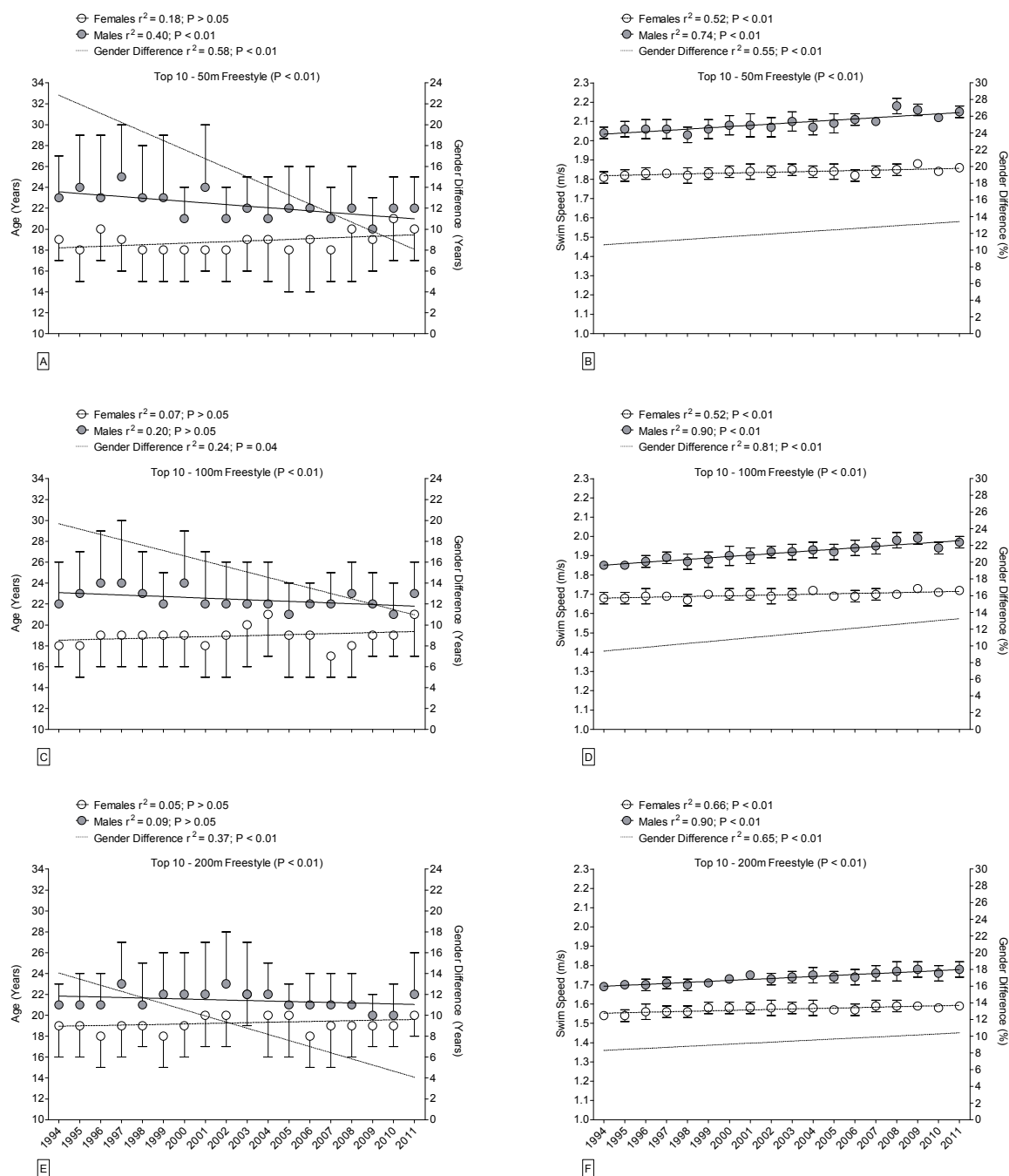


Fig. 2. Age (Panels A,C,E) and swimming speed (Panels B,D,F) of the annual top ten women and men and the sex difference for freestyle in 50m, 100m and 200m

Table 3. Change in peak swimming speed of the annual ten fastest swimmers for women and men from 1994 to 2011. The percentage of increase of peak swimming speed is given for both sexes and both butterfly and freestyle from 1994-2011.

Distance	Women			Men		
	1994 (m/s)	2011 (m/s)	%	1994 (m/s)	2011 (m/s)	%
Butterfly						
50m	1.64±0.04	1.76±0.03	7.32	1.85±0.02	1.98±0.02	7.03
100m	1.52±0.01	1.60±0.04	5.26	1.70±0.03	1.81±0.03	6.47
200m	1.36±0.04	1.41±0.05	3.68	1.51±0.02	1.59±0.04	5.30
Freestyle						
50m	1.81±0.03	1.86±0.02	2.76	2.04±0.03	2.15±0.03	5.39
100m	1.68±0.03	1.72±0.02	2.38	1.85±0.02	1.97±0.03	6.49
200m	1.54±0.02	1.58±0.02	3.25	1.69±0.01	1.78±0.04	5.33

speed was unchanged in men (~21 years in 1994 *versus* ~22 years in 2011) and women (~19 years in 1994 *versus* ~20 years in 2011).

Sex difference in peak swimming speed

From 1994 to 2011, the sex difference in swimming speed increased in all freestyle distances and over 100m butterfly. It showed additionally a trend towards a greater sex difference over 50m and 200m butterfly (Table 1). In butterfly, the sex difference in peak swimming speed decreased significantly over all distances (Figure 1 and Table 2). The sex difference in peak swimming speed decreased significantly for freestyle over all investigated distances (Fig. 2 and Table 1). Both women and men increased peak swimming speed for the annual ten fastest swimmers, but men more pronouncedly than women (Table 3). The swimming speed of the annual ten fastest athletes increased between 2.4% in 100m freestyle and 7.3% in 50m butterfly in women and between 5.3% in 200m butterfly and 7.0% in 50m butterfly in men (Table 3).

Discussion

The aim of the present study was to investigate during the 1994-2011 period for swimmers competing at national level (i) the change in the age of peak swimming speed across years for male and female top swimmers for butterfly and freestyle for 50m, 100m and 200m, respectively, and (ii) the change in peak swimming speed across years in 50m, 100m and 200m in butterfly and freestyle. The main findings were that the age of peak swimming speed increased for women from ~19 to ~21 years but not for men with ~22 years over all distances in butterfly. In freestyle, the age of peak swimming speed was constant for both sexes over all distances with ~20 years in women and ~21 years in men except for a decrease in the age of peak swimming speed in 50m freestyle in men to 22 in 2011. Peak swimming speed of both sexes increased for both butterfly and freestyle over all distances between 2.4% and 7.3% in women and between 5.3% and 7.0% in men.

Change in the age of peak swimming speed

The age of peak swimming speed was constant for both women (~19 years) and men (~21-22 years) in freestyle and for men in butterfly (~22 years). Only in women, the age of peak swimming speed increased in butterfly from ~18-19 years to ~20-21 years. These findings differ from the findings reported by Schulz and Curnow [4]. These authors reported the age of peak swimming speed for female swimmers at ~17 years, for male swimmers at ~19 years, respectively. These different findings might be due while Schulz and Curnow analysed data from 1886 to 1980, and we analysed data from a later period of 1994 to 2011. In freestyle, the age of peak swimming speed was constant

for both sexes across all distances with exception of the 50m for women. It seemed as if the age of peak swimming speed increased across years for butterfly but not for freestyle in women.

A possible explanation for these different findings might be the relative youth of butterfly swimming as it was introduced as the last swim modality by FINA [5]. Therefore, the limit of the age of peak swimming speed might not be reached by now. However, this will not explain why men's age of peak swimming speed was constant in both disciplines. Other reasons for these findings might be anthropometric characteristics predicting swimming speed such as body height [23-25]. Since anthropometry of an athlete changed across lifetime [26,27], certain years of life may favour elite swimming performance. Geladas et al. [24] examined the relationship between anthropometry, physical capacity, and sprint swimming speed in swimmers of both sexes aged 12-14 years old. Upper extremity length, horizontal jump, and grip strength were detected as significant predictors of 100m freestyle swimming speed in boys. In girls, body height, upper extremity and hand length, shoulder flexibility, and horizontal jump were all significantly related to 100m freestyle time but the degree of association was markedly lower than in boys. Zampagni et al. [28] determined in elite master swimmers of both sexes using anthropometric variables and the hand grip strength measure (i) whether it was possible to predict freestyle swimming speed time, (ii) whether the considered predictors were related similarly to different events (*i.e.* 50m, 100m, 200m, 400m, and 800m, respectively), and (iii) whether they were the same in man and women master swimmers. Age, height, and hand grip strength were the best predictors in short-distance events, whereas only age and height were predictors in middle- and long-distance events. Differences between sexes were not found in 50m event, but were present in all other events. Why a higher age favours women but not men in butterfly swimming remains unexplained and needs further investigations.

Sex difference in the age of peak swimming speed

The age of peak swimming speed was higher in men than women across both disciplines and all distances. An explanation for the different ages of peak swimming speed between women and men could be body fat as predictor variable for swimming speed [27,29,30]. Siders et al. [29] reported that measurements of body composition such as body fat and body mass may be predictors of swimming speed in women but not in men. Tuuri et al. [30] showed that a greater fat mass in female swimmers was more strongly related to lower levels of exercise. Bitar et al. [26] reported that during the onset of puberty, boys and girls gained fat-free mass, whereas fat mass gain was higher in

girls than in boys. Lean body mass, which primarily reflects muscle mass, begins to increase during early puberty in both boys and girls. Fat mass, however, increases during the late stages of puberty in girls [31]. A further increase in fat mass after puberty may impair swimming speed in women. Zuniga et al. [27] showed that boy and girl sprint swimmers at the age of ~11 years were different for percent body fat (*i.e.* boys $9.4 \pm 5.4\%$ fat and girls $12.7 \pm 6.2\%$ fat, respectively) and suggested that swimming speed for girls may be improved through training programs designed to reduce body fatness.

Furthermore, maturation is earlier in women than in men [31,32]. This can be seen in bone growth during puberty in relation to physical growth [33]. Maximal increase of all bone variables occurred earlier in girls than in boys and earliest for bone width, then mineral content, then density. By age the age of ~17 years, boys had attained 86% of the reference adult bone mineral content and volumetric density; girls had attained 93% of the reference adult bone mineral content and 94% of volumetric density. A recent study on the growth of the metacarpal bones showed a difference of ~2 years in the growth pattern between boys and girls [32]. Furthermore, hormonal changes during puberty seemed to have a great impact on anthropometry as boy's rise of testosterone influenced muscle mass [34]. Therefore, the older age of peak swimming speed of men seemed to be due to anthropological and physiological reasons.

The fastest swimmers became faster across years

Both women and men significantly improved swimming speed during the period from 1994 to 2011 over all distances. However, men were faster than women in both butterfly and freestyle across all distances. Anthropometric characteristics and their changes across years may explain differences in swimming speeds between the sexes and the time periods. Kagawa et al. [35] analysed the changes in growth between 1900 and 2000 in Japanese children from the age of 6 to 17 years. Over the 100-year period, body height and body weight of both sexes in Japanese children increased across years. Body height increased by 1.0-2.0 cm per decade and body weight by 0.4-1.7 kg per decade in boys whereas girls had rates of 1.1-1.9 cm and 0.4-1.5 kg per decade, respectively. The rates of height increment were significantly different between pre-, during and post-World War II periods. While Japanese children were considerably larger in 2000 compared to 1900, increments between 1950 and 1960 reflected catch-up growth to restore physical size seen in children prior to World War II. The increase in body size continued after 1960 with greatest changes seen across the pubertal years.

When changes in body dimensions were analysed for recent decades, Simsek et al. [36] reported a sig-

nificant secular increase from 1993 to 2003 in body weight and body height measurements in 7- to 15-year-old boys and girls in Ankara, Turkey. Also Marmo et al. [37] showed an increase in body height and body weight between 1979/80 and 1993/94 for both boys and girls in São Paulo, Brazil.

However, there seems to be a levelling-off of the changes in body height and body weight. Kurokawa et al. [38] monitored the secular changes in growth status among the 6th year children in primary schools (11-12 years old) and 3rd year children in junior high schools (14-15 years old) in the city of Sendai, Japan, since 1934. After World War II, both primary school children and junior high school students showed marked increases in body height and body weight up to the early 1970s. Acceleration and the subsequent reduction in the degree of acceleration in growth were observed in 1965-1974 and 1975-1984, respectively, and were followed by reacceleration in 1985-2005. The period between 1985 and 1999 was characterized by positive trends both in body height and body weight among schoolchildren. However, the degree of the increases in body height and body weight was diminished between 1999 and 2003.

During the last century, there have also been changes in periods of increased and decreased intensity of acceleration of physical development. Krawczynski et al. [39] investigated changes in body height and body weight in children and adolescents in Poznan, Poland, between 1880 and 2000. They reported periods of increased and decreased intensity of acceleration of physical development (the 1950s and 1970s, and the 1960s and 1980s, respectively), as well as a period of deceleration (the 1940s). In the last decade, the tendency has been towards deceleration in most age groups.

Sex difference in swimming speed across years

Apart from the change of the age in peak swimming speed across the years, we also analysed the change in sex difference in maximal swimming speed over time. For all disciplines, the sex difference decreased with increasing length of the swimming speed. Regarding the sex difference for butterfly in 2011, the sex difference decreased from ~12% (50m) to ~9% (200m). In freestyle, the sex difference decreased from ~13% (50m) to ~10% (200m) in 2011. Nevill et al. [3] reported similar findings for freestyle as the sex difference in swimming speed decreased with increasing distance. For the 100m freestyle swimming world records from 1957 to 2006, the sex difference was at 11%, for the 200m freestyle at 10% and for the 400m freestyle at 9%. However, the analysis suggested that the sex difference in swimming speed remained stable between 8% and 11% [3].

In contrast, an important finding of the present study was that sex difference increased over all free-

style distances and over 100m butterfly over time. A possible explanation for this finding provided Seiler et al. [40]. They investigated the fall and the rise of the sex difference in elite swimming speeds in running, swimming and speed skating from 1952 to 2006. They reported a narrowing of elite swimming speeds of both sexes until the early 90's, followed with a rise ever since then. Furthermore, the widening of the sex difference in swimming speed coincided with dramatic improvements in the scope and sensitivity of drug testing. Nevertheless, the phenomena of the fall and the rise of sex difference in elite swimming speeds need further evaluation.

Strength, weakness, limitations and implications for future research

The strength of the study is the completeness of the data from 1994-2011. The weakness could be that these results only represent distances from 50m to 200m. As butterfly events normally are held from 50m to 200m, the comparison between butterfly and freestyle swimming is limited. The study is limited since variables such as physiological parameters [18], anthropometric characteristics [27], training data [41], nutrition [42,43], and motivational [44] factors were not considered. These variables may have had an influence on race outcome. Future studies need to investigate elite butterfly swimmers competing at international level such as the Olympic Games and the World Championships. Also, the trend in the decrease of the sex difference in swimming speed with increasing race distance above 400m to 1,500m as in 5km, 10km or 25km competitions should be investigated. Furthermore, future studies need to evaluate the differences of water and air-based sports as sex difference in swimming speed could be influenced by the difference of the two mediums.

Conclusions

Elite Swiss swimmers became faster across years from 1994-2011 in both freestyle and butterfly over distances of 50m, 100m and 200m. Although the sex difference in swimming speed decreased with increasing race distance for both freestyle and butterfly, it increased across years in freestyle over 50m, 100m and 200m and in butterfly in 100m. The sex difference was ~12% and therefore appeared similar to those observed by other studies. For both butterfly and freestyle, the age of peak swimming speed was ~19 years for women. For men, the age of peak swimming speed was at ~22 years over all distances. Although the age of peak swimming speed increased for women but not for men in 50m, 100m and 200m butterfly, the fastest women were younger than the fastest men. In freestyle, the age of peak swimming speed was constant for both sexes with exception of the 50m freestyle in men. The

present results showed that peak swimming speed was not reached yet while the age of peak swimming speed was levelling at constant ages. This suggests for both athletes and coaches that there are still possibilities for further improvements in performance.

Declaration of interest

The authors report no conflicts of interest.

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